

**WHAT IS CLAIMED IS:**

1. An engine with variable cycle switchable between a 4-cycle mode and a 2-cycle mode, the engine comprising:

5 a plurality of combustion chambers each including a cylinder, a piston, an intake valve and an exhaust valve provided in the cylinder, a fuel injection unit for injecting fuel into the cylinder, and an ignition unit for ignition of the fuel within the cylinder; and

a controller that controls an operation of the intake valve, the exhaust valve, the fuel injection unit, and the ignition unit, the controller:

10 executing a plurality of operation modes in accordance with a combination of one of the 4-cycle mode and the 2-cycle mode with one of a combustion ignition control and a self ignition priority control, the combustion ignition control performing an ignition with the ignition unit at a predetermined timing before top dead center of the piston, and the self ignition priority control  
15 performing one of the ignition without the ignition unit and the ignition with the ignition unit at a timing delayed from the predetermined timing under the combustion ignition control; and

performing at least one transition cycle upon switching of an operation mode of the engine between a first operation mode and a second operation  
20 mode, the first operation mode being performed before the switching, the second operation mode being performed after the switching, and the transition cycle performing an operation of a same cycle type as the second operation mode under the combustion ignition control, wherein:

25 the transition cycle is different from the second operation mode in at least one of an intake valve opening timing, an intake valve closing timing, an exhaust valve opening timing, an exhaust valve closing timing, an injection quantity of the fuel, and an injection timing of the fuel; and

the combustion ignition control is executed in one of the combustion chambers where a single cycle of the transition cycle is terminated until  
30 each of all the combustion chambers terminates a single cycle of the transition cycle irrespective of the second operation mode under one of the combustion ignition control and self ignition priority control.

2. The engine according to claim 1, wherein:

the first operation mode comprises the 2-cycle mode;

the second operation mode comprises the 4-cycle mode under the combustion ignition control;

each of the transition cycle and the second operation mode has an overlap period at which both the intake valve and the exhaust valve are opened;

5 and

the intake valve opening timing in the transition cycle is delayed from the intake valve opening timing in the second operation mode.

3. The engine according to claim 1, wherein:

10 the exhaust valve opening timing in the transition cycle is set to a predetermined timing that is close to the exhaust valve opening timing in the first operation mode; and

the fuel is injected in the first operation mode upon a transition from the first operation mode to the transition cycle, and the exhaust valve is opened in the transition cycle after combustion of the fuel.

15 4. The engine according to claim 1, wherein:

the first operation mode comprises the 2-cycle mode;

the second operation mode comprises the 4-cycle mode; and

20 the controller opens the exhaust valve of one of the combustion chambers in the transition cycle subsequent to combustion of the fuel injected in the first operation mode upon transition from the first operation mode to the transition cycle, and opens the exhaust valve of the other combustion chamber in the transition cycle at a timing  $720^\circ/\text{N}$  delayed from the timing at which the exhaust valve is opened in the transition cycle in the one of the combustion chambers where the transition cycle is started.

25 5. The engine according to claim 1, wherein:

the first operation mode comprises the 2-cycle mode under the self ignition priority control;

the second operation mode comprises the 4-cycle mode under the self ignition priority control; and

30 an actual compression ratio in the transition cycle is higher than the actual compression ratio in the second operation mode.

6. The engine according to claim 5, wherein the intake valve closing timing in the transition cycle is earlier than the valve closing timing in the second operation mode.

7. The engine according to claim 1, wherein:

the first operation mode comprises 2-cycle mode under the self ignition priority control;

5 the second operation mode comprises the 4-cycle mode under the self ignition priority control; and

the exhaust valve closing timing in the transition cycle is earlier than the exhaust valve closing timing in the second operation mode.

8. The engine according to claim 7, wherein:

10 each of the transition cycle and the second operation mode has a period at which the intake valve and the exhaust valve are kept closed from closing of the exhaust valve to opening of the intake valve; and

the intake valve opening timing in the transition cycle is delayed from the intake valve opening timing in the second operation mode.

9. The engine according to claim 1, wherein:

15 the first operation mode comprises the 4-cycle mode;

the second operation mode comprises the 2-cycle mode; and

20 the injection quantity of the fuel in the transition cycle is in a range between  $1/2$  and  $2/3$  of the injection quantity of the fuel injected by the fuel injection unit in the first operation mode, and the period from opening of the exhaust valve to opening of the intake valve in the transition cycle is shorter than the period in the second operation mode.

10. The engine according to claim 1, wherein:

the first operation mode comprises the 4-cycle mode under the self ignition priority control;

25 the second operation mode comprises the 2-cycle mode under the self ignition priority control; and

a period taken from opening of the intake valve to closing of the exhaust valve in the transition cycle is longer than the period in the second operation mode.

30 11. The engine according to claim 1, wherein:

the first operation mode comprises the 4-cycle mode under the self ignition priority control;

the second operation mode comprises the 2-cycle mode; and

an actual compression ratio in the transition cycle is lower than

the actual compression ratio in the second operation mode.

12. The engine according to claim 1, wherein:

the first operation mode comprises the 4-cycle mode under the combustion ignition control;

5 the second operation mode comprises the 4-cycle mode under the self ignition priority control; and

the exhaust valve closing timing in the transition cycle is delayed from the exhaust valve closing timing in the second operation mode.

13. The engine according to claim 1, wherein:

10 the first operation mode comprises the 4-cycle mode under the combustion ignition control;

the second operation mode comprises the 4-cycle mode under the self ignition priority control; and

15 an actual compression ratio in the transition cycle is lower than the actual compression ratio in the second operation mode.

14. The engine according to claim 1, wherein:

the first operation mode comprises the 4-cycle mode under the self ignition priority control;

20 the second operation mode comprises the 4-cycle mode under the combustion ignition control; and

an actual compression ratio in the transition cycle is higher than the actual compression ratio in the second operation mode.

25 15. An engine with variable cycle switchable between a 4-cycle mode and a 2-cycle mode in which an area defined by a required load and an engine speed is divided into a first area where the required load is higher than a predetermined value, a second area where the required load is lower than the predetermined value, a third area between the first area and the second area, where the engine speed is lower than a predetermined value, and a fourth area between the first area and the second area, where the engine speed is higher than the predetermined value, the engine  
30 comprising:

a first operation mode performed in the first area and the second area, and the engine is operated in the 4-cycle mode under a combustion ignition control with an ignition unit at a predetermined timing before top dead center of a piston of the engine;

a second operation mode performed in the third area, and the engine is operated in the 2-cycle mode under a self ignition priority control that executes one of the ignition without the ignition unit and the ignition with the ignition unit at a timing delayed from the timing under the combustion ignition control; and

5 a third operation mode performed in the fourth area, and the engine is operated in the 4-cycle mode under the self ignition priority control.

16. A method of switching an operation mode of an engine with a plurality of combustion chambers and a variable cycle switchable between a 4-cycle mode and a 2-cycle mode among a plurality of operation modes, the plurality of operation  
10 modes including a combination of one of the 4-cycle mode and the 2-cycle mode with one of a combustion ignition control and a self ignition priority control, the combustion ignition control performing an ignition with an ignition unit at a predetermined timing before top dead center of a piston of the engine, and the self  
15 ignition priority control performing one of the ignition without the ignition unit and the ignition with the ignition unit at a timing delayed from the predetermined timing under the combustion ignition control, in each of the plurality of combustion chambers, the method comprising the steps of:

(a) executing a first operation mode before switching of the operation mode;

(b) executing a second operation mode after switching of the operation mode;

20 and

(c) executing at least one transition cycle between the first operation mode and the second operation mode, the transition cycle having a same cycle type as the second operation mode, wherein:

25 the transition cycle is different from the second operation mode in one of an intake valve opening timing, an intake valve closing timing, an exhaust valve opening timing, and an exhaust valve closing timing, a fuel injection quantity, and a fuel injection timing; and

30 the step (b) includes an execution of the combustion ignition control in one of the combustion chambers having a single operation of the transition cycle completed until the single operation of the transition cycle is terminated in each of all the combustion chambers in the step (c) irrespective of the second operation mode under one of the combustion ignition control and the self ignition priority control.

17. A method of operating an engine with variable cycle switchable

between a 4-cycle mode and a 2-cycle mode in which an area defined by a required load and an engine speed is divided into a first area where the required load is higher than a predetermined value, a second area where the required load is lower than the predetermined value, a third area between the first area and the second area, where the engine speed is lower than a predetermined value, and a fourth area between the first area and the second area, where the engine speed is higher than the predetermined value, the method comprising the steps of:

- 5 (a) performing the 4-cycle mode in at least one of the first area and the second area under a combustion ignition control with an ignition unit at a predetermined  
10 timing before top dead center of a piston of the engine;
- (b) performing the 2-cycle mode in the third area under a self ignition priority control that executes one of the ignition without the ignition unit and the ignition with the ignition unit at a timing delayed from the timing under the combustion ignition control; and
- 15 (c) performing the 4-cycle mode in the fourth area under the self ignition priority control.